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Acoustic design of open-plan offices and comparison of requirements in the Nordic countries

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In the Nordic countries, most office buildings include open-plan offices. However, to optimize working conditions, such spaces require special acoustic design to obtain reasonable sound attenuation between groups and satisfactory speech intelligibility internally in groups, although optimal working conditions can never be expected. This paper describes and compares the current requirements and recommendations in the Nordic countries for such open-plan offices and presents the design and measurements from two Danish office buildings. The results from room acoustical modelling, measurements and subjective evaluation are presented and evaluated in relation to current requirements and recommendations. Furthermore, the applicability of different criteria in a typical design and building process - until the offices are in use - are discussed, and some suggestions made for future acoustic regulations and guidelines for open plan offices.

1 Introduction

The opinions on open-plan offices' success are divided and especially noise, annoyance and acoustics in open-offices are debated in media and professionally. Guidelines on the room acoustics in open-plan offices has existed for years in many/some Nordic countries. Internationally, the ISO 3382-3 [1] has established methods that carefully describes – and gives recommendations to – the acoustics in open-plan offices. But even in this standard there may be room for improvements. Based on a state-of-the-art review on the present status concerning acoustic guidelines in the Nordic countries it is discussed, if these guidelines are appropriate to ensure satisfactory or good acoustic conditions for the users. As a contribution to this debate two cases about Danish open-plan offices are analysed for different aspects of acoustics. In the first case, the offices are analysed straightforward (equivalent absorption area and sound propagation). In the other case, the Speech Transmission Index and its dependency on distance and background noise are analysed.

2 Methods to describe acoustics in open-plan offices – ISO 3382-3

Sound fields in open-plan offices are not diffuse, and can thereby not be described solely with average values on reverberation time [2] or absorption areas. The spatial variation in reverberation time (RT), equivalent absorption areas (A), sound pressure level (SPL) and speech intelligibility (STI) in open offices can be considerable – and the perceived acoustic variations as well [3]. The ISO 3382-3 addresses these conditions whereas it focuses on the damping of the sound propagation and the influence on amplification and speech intelligibility due to the open plan. Actually, the ISO 3382-3 uses the following terms (popular description in brackets): Spatial decay rate of A-weighted SPL of speech, $D_{2,S}$ in dB (sound propagation), A-weighted SPL of speech at 4 metres $L_{p,A,S,4m}$ in dB (room amplification), the A-weighted background noise level $L_{p,A,B}$ and – optional – Speech Transmission Index, STI in the nearest workstation (degree of comprehensibility), Distraction distance r_D in m (distance where $STI = 0,5$) and the privacy distance r_P in m (distance

where $STI = 0,2$). Concerning definition of STI, see [4]. The $D_{2,S}$ -definition is an application of DL_2 defined in [5]. In [1], Annex A, are found examples of target values for evaluation of measurement data; two sets of acoustic criteria for open-plan offices with poor and good acoustic conditions, respectively. Most open-plan offices have poor or insufficient acoustic conditions.

Example open-plan office with poor acoustic conditions: Typical single number values have

$$D_{2,S} < 5 \text{ dB}, L_{p,A,S,4m} > 50 \text{ dB}, \text{ and } r_D > 10 \text{ m}. \quad (1)$$

Example open-plan office with good acoustic conditions:

$$D_{2,S} \geq 7 \text{ dB}, L_{p,A,S,4m} \leq 48 \text{ dB}, \text{ and } r_D \leq 5 \text{ m}. \quad (2)$$

The acoustic regulations and recommendations for open-plan offices in the Nordic countries are found in Section 3.

3 Acoustic regulations and recommendations for open-plan offices

In most building codes, there is a general statement about requiring satisfactory acoustic conditions for health and/or comfort reasons. This Section deals with the interior of open-plan offices only, i.e. the below information for the five Nordic countries is about room acoustic conditions and noise levels from service equipment.

3.1 Denmark

In Denmark, the most recent building code is [6], and the chapter about acoustics is Ch. 17 with functional requirements, without limit values. Concerning acoustic limit values is referred to a guideline [7], which includes regulatory requirements for housing, educational buildings and kindergartens. There are no fixed regulatory acoustic requirements for other buildings and thus neither for office buildings nor for open-plan offices. However, a few basic recommendations have been included for offices. For open-plan offices is recommended $L_{A,eq,30s} \leq 35$ dB and the equivalent sound absorption area $A \geq 1.1 \times \text{Floor area (m}^2\text{)}$, frequency range 125-4000 Hz, both limit values for furnished rooms.

Since [6] is new (Dec. 2017), a general SBI-guideline has not yet been completed replacing the guideline [10] for the previous regulations [8]. In [10] it is recommended to have $STI \leq 0.3$ between workstations in office areas and to have $D_{2,S} \geq 5$ dB, and this type of limit values will also be defined for the revised guidelines.

3.2 Finland

In Finland, there are no regulatory acoustic requirements for open-plan offices in the Building Code [11]. However, in the voluntary acoustic classification scheme [12], which has four classes A-D with class C in general supposed to correspond to regulation level, there are reverberation time limits defined with $T \leq 0.45$ s for rooms with height below 3 m and $T \leq 0.50$ s for rooms with height above 3 m, furnished rooms. The service equipment noise level should be in the range 40...42 dB, since it is recommended that open plan offices have a higher background noise level than single person office rooms, so that unnecessary vocal noises are less heard, and reference is made to and Annex D, *Acoustic planning of open-plan offices*. In Annex D is stated that “*the most common reason for disturbances in an open-plan office are speech sounds originating from the neighbouring workstations. In order to minimize the disturbance, a low Speech Transmission Index STI between the workstations and simultaneously a low level of voices must be the aim. This means that the following three steps must be put into effect at the same time:*

- *Maximum sound absorption of the ceiling, for 100 % of the floor area*
- *Sufficiently high office screens, preferably more than 150 cm high*
- *A sound which masks speech effectively, without being a disturbance, usually at a level of 40-45 dB (A)”.*

In Annex C, *Speech intelligibility used to determine room acoustics quality*, there is a table defining the subjective meaning of STI, range 0-1, for speech intelligibility and speech privacy, respectively.

3.3 Iceland

The building code [13] refers to fulfilment of class C in IST 45 [14], which includes all types of buildings, including office buildings. For open-plan offices is required reverberation time $T \leq 0.50$ s. For service equipment noise is required $L_{p,Aeq,T} \leq 35$ dB and $L_{p,Ceq,T} \leq 55$ dB.

In an informative Annex B are found some additional recommendations, among others $D_{2,S} \geq 7$ dB and STI limit $\leq 0,2$ values between groups and $\geq 0,6$ with background noise inside groups, cf. [14].

3.4 Norway

The building code [15] refers to fulfilment of class C in NS 8175 [16], which includes all types of buildings, including office buildings.

For open-plan offices is required reverberation time $T \leq 0.16 \times h$ (s), h = room height. For service equipment noise is required $L_{p,A} \leq 35$ dB and $L_{p,AF,max} \leq 55$ dB.

In an informative Annex E are found some additional hints, warnings and recommendations, among others $D_{2,S} \geq 7$ dB and STI limit values between and inside groups, cf. [16].

The following warning is given in [16]: “*Open-plan offices, large rooms and areas partitioned by screens are in terms of acoustics ill-suited for providing functions that have differing and somewhat conflicting needs. For example, where there is a need for communication and in the same time a need to perform concentrated work without disruption, or without overhearing speech and telephone calls, open-plan spaces are less suited.*”

Concerning the criteria in Table E.1 in Annex E, it is stated: “*Knowledge concerning the application of these criteria is still developing. The values specified in table E.1 are based on current knowledge and are therefore to be taken as guideline values. If better data are available, more recent values may be used.*”

3.5 Sweden

The building code [17] refers to fulfilment of class C in SS 25268 [18], which includes several types of buildings, including office buildings.

For open-plan offices is required reverberation time $T \leq 0.50$ s. For service equipment noise is required $L_{p,A} \leq 35$ dB and $L_{p,C} \leq 55$ dB.

4 Open-plan office for cognitive work

The first case is about open-plan offices in a knowledge-based company with several departments, in which the tasks mainly are cognitive and requires a high degree of concentration.

The departments are in the same building and therefore the basic physical conditions are alike, i.e. ceiling height and building materials (ceiling-, wall- and floor-surfaces). Two of the departments are presented in this paper as shown on Figure 1. The differences between the two departments are solely their floor-area (305 and 220 m² in department A and C, respectively) and, more important the height and density of the furniture, as book shelves and room dividers in department A are lower than in department C.

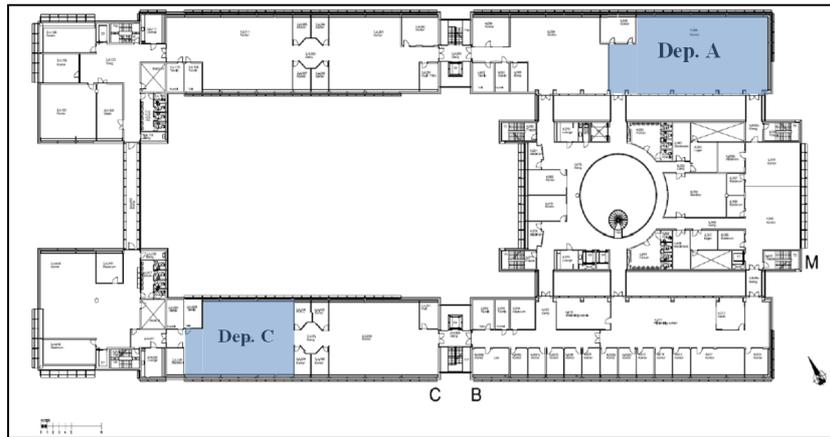


Figure 1. Open office for cognitive work - department A and C.

Both departments have identical room heights: 2,7 m and surfaces. Ceiling: Perforated Gypsum. Walls: Windows, painted gypsum and concrete. Floor: Linoleum.

The Danish recommendation for acoustics in open-plan offices ($A \geq 1,1 \times \text{Floor area}$) is not fulfilled in department A (Measured/required absorption area: $A = 279/335 \text{ m}^2$) while the acoustics in department C just precisely fulfils the requirement ($A = 241 \text{ m}^2$). Because the acoustics in both offices must be improved – due to complaints from users – some preliminary measurements of sound propagation in both departments were performed according to ISO 3382-3 concerning $D_{2,S}$ and $L_{p,A,S,4m}$. Figure 2 and Figure 3 show plans with measured propagation paths and diagrams for the sound propagation and calculated $D_{2,S}$ in the departments A and C.

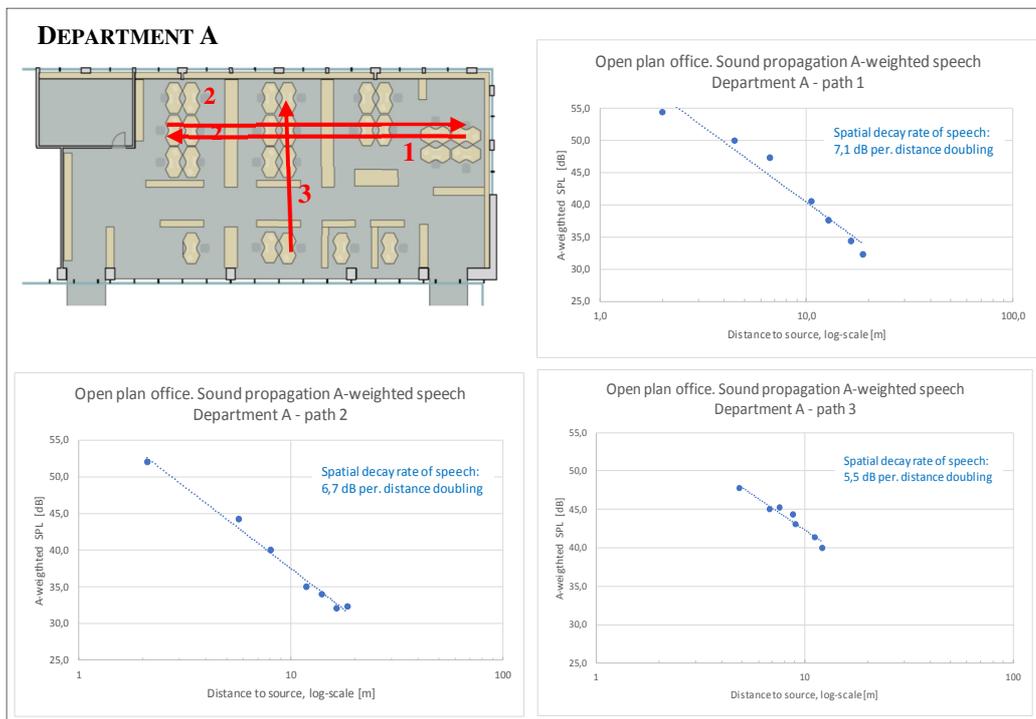


Figure 2. Measured sound propagation in department A with sound paths 1, 2 and 3. $D_{2,S}$ varies from 5,5 to 7,1 dB and the average is 6,4 dB.

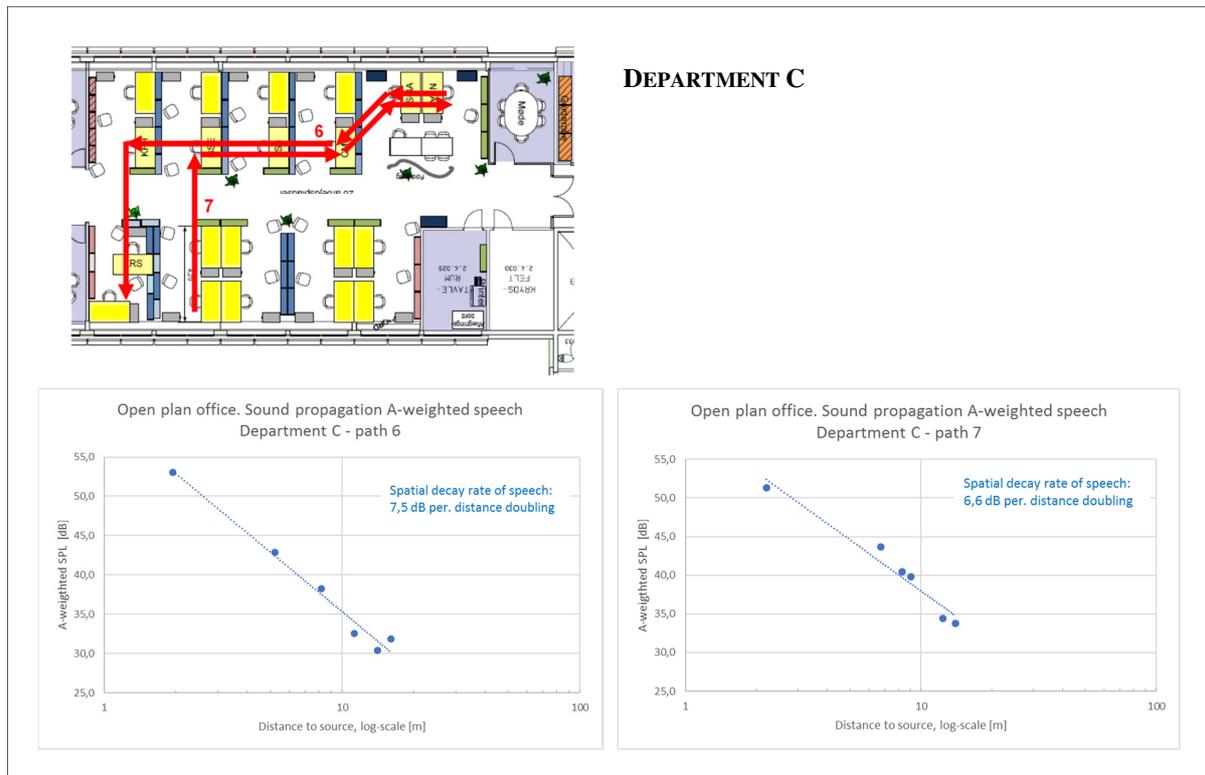


Figure 3. Measured sound propagation in department C with sound paths 6 and 7. $D_{2,S}$ varies from 6,6 to 7,5 dB and the average is 7,1 dB.

As shown the $D_{2,S}$ is higher (better) in department C compared to department A. The absolute $D_{2,S}$ -values in department A on average are lower than $D_{2,S} = 7$ dB, which according to ISO 3382-3 is an example on a target value for one of the parameters, which must be fulfilled in an open-plan office with good acoustic conditions. In department C the average value of $D_{2,S}$ is just above 7 dB. Contributory cause to this is the screening effect of furniture. Supplementary analysis shows the room amplification represented by $L_{p,A,S,4m}$ in the two departments varies between 46 og 50 dB in department A and between 45 og 47 dB in department C. The ISO 3382-3 target value for $L_{p,A,S,4m}$ in offices with good acoustic conditions is (below) 48 dB. Again, the tendency is that department C is better than department A. The higher SPL-values for speaking persons in department A compared with department C agrees well by the before-mentioned reverberation time or sound absorption measurements, where department A were short of absorption and thereby theoretically should have higher SPL. These results can be used when designing proposals to supplementary damping between the working groups, where especially damping of sound propagation (screening) across the departments are important. For department A also extra absorption is important. Although there may be limitations for the acoustical improvements. In summary, it can be concluded that the methods concerning sound propagation and amplification in ISO 3382-3 are highly useable.

5 Open-plan office – Call centre

The second example concerns a Call centre in which absorption measurements also showed lack of absorption but here we will focus on two parameters related to comprehensibility or intelligibility (STI, the Speech Transmission Index) between workplaces. The parameters are Distraction distance r_D in m (distance where $STI = 0,5$) and the Privacy distance r_P in m (distance where $STI = 0,2$). The office is shown in Figure 4.



Figure 4. Plan of the Call centre and the chosen sound path.

As the original acoustics was inappropriate an improvement suggestion was made, involving absorption and screens. By these means the total absorption area will fulfil the requirement and the sound propagation will be more dampened. The question is how much? Using the Odeon room acoustic software, it is calculated that the STI still decreases relatively slowly along the row of workplaces following the sound path in Figure 4. Actually, in the Call centre with technical background noise levels measured as low as 29 dBA, you need more than 10 meters to reach the point where $STI = 0,5$ since the $r_D = 16$ m as shown in Figure 5. Even though there may be some uncertainties in a simulation 16 m still seems as a large distance, especially if you compare with the ISO 3382-3 target value for $r_D \leq 5$ m in offices with good acoustic conditions.

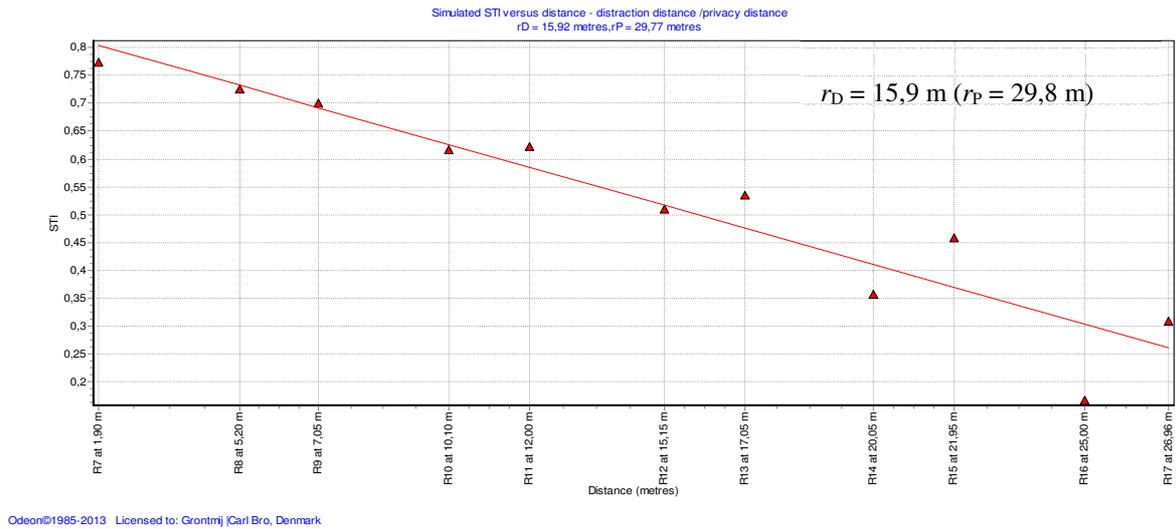


Figure 5. Calculated STI vs. distance in a dampened situation in the Call centre with technical background noise.

In ISO 3382-3 it is stated that the measurement conditions must be furnished room without the presence of people. For background noise measurements applied for the determination of STI-values, the HVAC and other technical equipment must operate normally. In this paper we recommend that the noise from people talking/working in the room is included – because it may cause a positive masking effect, which will lead to reduced values of r_D and r_P . All human presence causes some sort of noise. Therefore, it seems logical to include at least some of the human noise when calculating the STI in a room acoustic simulation. In [19] it is shown – based on measurements in several offices – that $L90_{HN}$, the background noise level exceeded in 90 % of the measured time from human activities in open offices, can be described by the formula (3) in the 500 Hz octave band:

$$L90_{HN} = 33.1 + 14.3 \cdot \log(T_{20}) + 15.0 \cdot d_1 \quad [\text{dB}] \quad (3)$$

where T_{20} is the reverberation time (0,41 s in this Call centre), $d_1 = 1$ for Call centres and $d_1 = 0$ for other offices, in which the human activity noise is 15 dB lower than in Call centres.

The $L90_{HN}$ represents a statistical measure for background noise from all kind of human activity. The frequency dependence for the A-weighted $L90_{HN}$ at higher and lower octave bands (with 500 Hz as top values) can be approximated by a slope of ± 6 dB per octave. Using this information you get a human activity background noise level around 43 dBA. The linear octave band levels must be used to calculate the STI-values using simulations, and by doing so we get a new $r_D = 6,5$ m as shown in Figure 6 Compared to the r_D with technical background noise (16 m), the 6,5 m seems more appropriate.

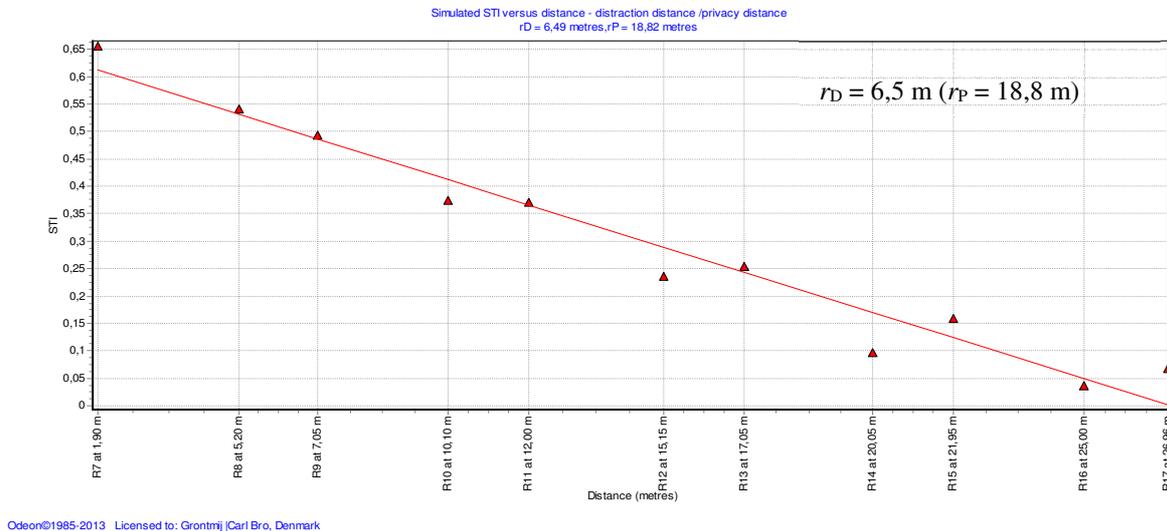


Figure 6, Calculated STI vs distance in a dampened situation in the Call centre with human activity background noise.

6 Discussion and conclusions

The paper has shown that there might be need for more mandatory rules on acoustics in open-plan offices to ensure better conditions for the office users, at least in DK. Here it could make sense to align the recommendations so $D_{2,S} \geq 7-8$ dB instead of the 5 dB as is now. Also, the recommendation on STI-values between workgroups should be aligned to $STI = 0,2$. The methods for sound propagation and room acoustical amplification described in ISO 3382-3 seems appropriate. On the other hand, in the standard you miss the natural contributions from human activity noise, A proposal for this is given. In practice, it is a problem that requirements for equivalent absorption area applies for furnished rooms while you – most often – built/deliver an empty house. One way to address this during the acoustic project work is to share the amounts of absorption that the user and the builder contributes with i.e. 10% to the user and 90% to the builder. As stated in ISO 3382-3 it is necessary to maintain that control measurements always must be performed in furnished rooms. A discussion between Nordic colleagues about experiences on rules, arrangement and use of open-plan offices would be useful as well as finding the balance between openness and work function. Not all tasks can benefit from – some work functions suffer in - open-plan offices. One also could consider discussing with other countries about their experience, e.g. Germany and France. In Germany, there is a draft standard [20], and in France there is a standard [21] about acoustics in office buildings and with sections on open-plan offices. Maybe one could benefit by experiences from open-plan schools, cf. [22] and based on that consider reviewing the requirements or recommendations in open-plan schools.

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